Attachment 4
Soils Stockpile Cover-Thickness Calculation Result
Fansteel Metals/ FMRI
Muskogee, Muskogee County, Oklahoma

	Type of Material	[1]Thickness of Layer (cm) (x)	[2]Porosity of Material (Unitless) (n)	[3]Density of Material (g/cm³) (ρ)	[4]Radon Emanation Coefficient (Unitless) (E)	[4]Radon Decay Constant (1/s) (λ)	[3]Long-term Average Moisture Content (Dry weight percentage) (w)	[4]Specific Gravity of Soils (Unitless) (G)
Contaminated Soils	Native soil	130	0.305660377	1.84	0.35	2.10E-06	10	2.65
Cover layer	Native soil	60	0.305660377	1.84	0.35	2.10E-06	10	2.65

	[3]Specific Activity of Ra-226 (pCi/g) (R)	[2]Moisture saturation fractions (Unitless) (m)	[2]Radon Diffusion Coefficients (cm²/s) (D)	[2]Inverse relaxation length (1/cm) (b)	[2]Interface constants (cm²/s) (a)	[4]Equilibrium distrubution Coffecient of Radon in Water and Air (pCi/cm³) (k)	[2]Radon Flux from the bare contaminated soil (pCi/m²-s) (Jt)	[2]Radon Flux from the Cover (pCi/m²-s) (Jc)
Contaminated Soils	88	0.6020	5.75E-03	0.0191	0.0002	0.2600	61	
Cover Layer	0.5	0.6020	5.75E-03	0.0191	0.0002	0.2600	0.3	**19.8**

NRC Radon Flux Limit: 20

[1]Thickness of cover layer was determined by trial and error in order to determine the maximum thickness with a Radon Flux result less than or equal to the NRC limit of 20 pCi/m2-s. A cover thickness of 60 centimeters is equivalent to 23.6 inches or 2 feet. The contaminated soil thickness of 130 centimeters = 51 inches = 4.25 feet. The radon flux calculated result remains the same (between 19.8 and 20.1 pCi/m²-s) beyond a thickness of 130 centimeters.

[2]Value calculated per NRC Regulatory Guide 3.64 formulas noted below. The NRC Regulatory Guide 3.64 formulas were designed with uranium mill tailings in mind; therefore, the subscripts 't' and 'c' in the formulas below refer to 'tailings' and 'cover', respectively. In this case, the formulas and terms with the 't' subscript are used for 'Contaminated Soils' and the formulas and terms with the 'c' subscript are used for 'Cover layer'.

[3]The Contaminated Soils Specific Activity of Ra-226 value equals highest soil sample result. 353 pCi/g is a subsurface soil sample (see Table 1-3) and Figure 1-16. The Cover Layer Specific Activity of Ra-226 value equals the mean of the West GSA BRA.

[4]Value obtained from NRC Regulatory Guide 3.64.

NRC Regulatory Guide 3.64 Radon Flux Formulas:

$$J_t = 10^4 * R * \rho * E * \sqrt{\lambda * D} * \text{hyperbolic tangent of } (x * \sqrt{\lambda/D})$$

$$J_c = \frac{2 * J_t * e^{-b_c * x_c}}{1 + \sqrt{a_t/a_c}}$$

$$D = 0.07 * e^{-4 * (m - (m * n^2) + (m^5))}$$

$$m = \frac{10^{-2} * \rho * w}{n * \rho_w} \; ; \rho_w \text{ is the mass density of water} = 1 \text{ g/cm3}$$

$$n = 1 - \frac{\rho}{G * \rho_w} \; ; \rho_w \text{ is the mass density of water} = 1 \text{ g/cm}^3$$

$$b = \sqrt{\lambda/D}$$

$$a = n^2 * D * (1 - ((1-k) * m))^2$$